NACA

RESEARCH MEMORANDUM

CARBON DEPOSITION FROM AN-F-58 FUELS IN A J33 SINGLE COMBUSTOR

By Jerrold D. Wear and Howard W. Douglass

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

June 24, 1949
Declassified August 18, 1954

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

CARBON DEPOSITION FROM AN-F-58 FUELS IN A J33 SINGLE COMBUSTOR

By Jerrold D. Wear and Howard W. Douglass

SUMMARY

An investigation was conducted using a single combustor from a 4600-pound-thrust turbojet engine to determine the amount of carbon deposition of AN-F-58 fuels and the effect of carbon formations in the combustor on the altitude operational limits. Three fuel blends conforming to AN-F-58 specification were prepared in order to determine the influence of boiling temperature and of aromatic content on carbon deposition. The carbon-forming tendencies of the three AN-F-58 fuels and of AN-F-32 fuel were compared at simulated altitudes of 20,000 and 35,000 feet, engine speed of 90-percent normal rated, and flight Mach number of 0.

Carbon deposition increased with increase in aromatic content and with increase in boiling temperature at constant aromatic content for the AN-F-58 fuels. The values of carbon deposition obtained with AN-F-32 fuel were exceeded only by the values obtained with the AN-F-58 fuel nearest the maximum specification limits of boiling temperature and aromatic content. Altitude operational limits of the high-aromatic AN-F-58 fuel occurred at slightly lower altitudes when the liner and dome assembly contained carbon deposits than when it did not. The ignition plug was fouled with carbon after 17 hours of intermittent operation with a fuel approaching the maximum limits of the AN-F-58 specification at a simulated altitude of 20,000 feet and 90-percent normal rated engine speed.

INTRODUCTION

The potential availability of AN-F-32 fuel for jet-propulsion engines is relatively small because of limitations in boiling range and composition. In order to increase the potential supply of fuel for jet-propulsion engines, fuel specification AN-F-58, which has wider limits, has been issued. A comprehensive program was undertaken at the NACA Lewis laboratory to determine the performance characteristics of fuels conforming to specification AN-F-58 in current turbojet engines and in single combustors from these engines.

In the single-combustor investigations (reference 1) special attention was given to the influence of physical properties and composition of AN-F-58 fuels on combustor performance in order to determine whether the limitations on physical properties and composition in the specification require revision.

The investigation reported herein was made to determine the effects of variations in boiling temperature and in aromatic content of fuels, within AN-F-58 specifications, on carbon deposition in a J33 single combustor. An AN-F-32 fuel was included for comparison with three AN-F-58 fuels.

Each fuel was investigated by making a series of runs of 2-, 4-, 6-, and 10-hour duration at simulated engine operating conditions of an altitude of 20,000 feet and 90-percent normal rated engine speed; a 6-hour run was made at an altitude of 35,000 feet and 90-percent normal rated engine speed. The effects of varying boiling temperature and aromatic content on carbon deposition are generalized by a correlation method reported in reference 2.

One AN-F-58 fuel was used to determine the effect carbon deposits have on the altitude operational limits of a fuel. The altitude operational limits were determined using an initially clean combustor liner and dome and also with a liner and dome that initially contained carbon deposits accumulated during 80 hours of operating time at a simulated altitude of 20,000 feet and 90-percent normal rated engine speed.

FUELS

Analyses and specifications for the fuels used in this investigation are presented in table I.

Three fuels conforming to AN-F-58 specification were used. The first of these (NACA fuel 48-249) was a uniform mixture of several tank-car lots of AN-F-58 fuel as received from the supplier. For purposes of the investigation, this fuel, which boiled between 110° and 560° F and contained 19 percent aromatics, was considered a base stock. A second AN-F-58 fuel (NACA fuel 48-258) was prepared by blending 92 percent of the base stock with 8 percent of a number 3 fuel oil. The resulting blend boiled between 110° and 590° F and contained 19 percent aromatics. This blend is hereinafter identified as the high-end-point fuel. Comparisons of these two fuels (NACA fuels 48-249 and 48-258) were intended to indicate the effect of fuel boiling temperature on turbojet-engine performance.

1113

A third AN-F-58 fuel (NACA fuel 48-279) was prepared by blending 79 percent of the base stock with 13 percent of redistilled hydroformate bottoms and 8 percent of number 3 fuel oil. The resulting blend boiled between 110° and 590° F and contained 29 percent aromatics. This blend is hereinafter identified as the high-aromatic fuel. Comparisons of NACA fuels 48-279 and 48-258 were intended to indicate the influence of aromatic content as well as fuel boiling temperature on turbojet-engine performance. As shown in table I, NACA fuel 48-279 approaches the maximum limit of the specification with respect to aromatic content and final boiling temperature.

Inasmuch as the silica-gel determination for aromatic content (table I) is considered more reliable than A.S.T.M. determinations for AN-F-58 fuels, all aromatic concentrations referred to are by the silica-gel method.

APPARATUS AND INSTRUMENTATION

A diagram of the general arrangement of the J33 single combustor and the auxiliary equipment is shown in figure 1. Air flow to the combustor was measured by a square-edged orifice plate installed according to A.S.M.E. specifications and located upstream of all regulating valves. The combustor-inlet-air temperature was regulated by use of electric heaters. The combustor-inlet-air quantities and pressures were regulated by remote-controlled valves in the laboratory air-supply and exhaust systems.

A diagrammatic cross section showing the combustor and its auxiliary ducting, the position of instrumentation planes, and the location of temperature- and pressure-measuring instruments in the instrumentation planes is presented in figure 2. Thermocouples and total-pressure tubes in each instrumentation plane were located at centers of equal areas. Construction details of the temperature- and pressure-measuring instruments are shown in figure 3.

Fuel flows to the combustor were measured by rotameters calibrated for each fuel. Pressure and temperature data were obtained by using manometers and potentiometers, respectively.

PROCEDURE

Carbon Deposition

The carbon-deposition characteristics of each fuel were determined by making runs of 2-, 4-, 6-, and 10-hour duration. The weight of carbon reported herein is the total amount that was deposited on the liner, dome, and ignition-plug assembly during any one run and represents the change in weight of this assembly during the run. These components of the combustor assembly were clean at the beginning of each run. The amount of carbon deposited on any one component was not determined.

The engine operating conditions simulated were those at altitudes of 20,000 or 35,000 feet, at 90-percent normal rated engine speed, and flight Mach number of 0. These conditions, which were obtained from the manufacturer's performance estimates of the compressor-turbine unit, are tabulated as follows:

	Altitude (ft)	
	20,000	35,000
Combustor-inlet total pressure, in. Hg absolute . . .	53.9	31.5
Combustor-inlet total temperature, °F	271	221
Mass air flow, lb/sec	2.87	1.66
Turbine-inlet total temperature, °F	1098	1073

Only 6-hour runs were made at the 35,000-foot altitude condition.

Fuel flow for each simulated engine condition was determined by adjusting the inlet-air conditions to the desired values and varying the flow of the base-stock AN-F-58 fuel (NACA fuel 48-249) until the required average turbine-inlet total temperature was obtained. These values of weight fuel flow were then used for all other fuels at the respective simulated engine conditions. The rates were 124.2 pounds per hour at the 20,000-foot-altitude condition and 78.9 pounds per hour at 35,000 feet.

Effect of Carbon Formations on Altitude Operational Limit

The altitude operational limit is defined as the altitude above which the combustor will not deliver sufficient temperature rise to operate the turbine at a designated rotational speed. The data for the selection of the required temperature rise at each condition were obtained from manufacturer's estimates at a Mach number of 0.

At each simulated engine rotational speed and altitude condition, the fuel flow was increased after ignition in an effort to obtain an average combustor-outlet (or turbine-inlet) temperature equal to or greater than that required for engine operation at those conditions.

The altitude operational limits of the high-aromatic AN-F-58 fuel (NACA fuel 48-279) were determined using an initially clean liner, dome, and ignition-plug assembly. The combustor was then intermittently operated for 80 hours at simulated engine operating conditions of an altitude of 20,000 feet and 90-percent normal rated engine speed. The altitude operational limits of the fuel were again determined; this time the liner, dome, and ignition-plug assembly contained carbon deposits accumulated during the 80-hour run.

CALCULATIONS

Combustion efficiencies were computed for the runs that provided the experimental points on the altitude-limit curves. Combustion efficiency is defined as

$$\frac{\text{actual enthalpy rise across combustor}}{\text{heating value of fuel supplied}}$$

Values for obtaining the enthalpy rise across the combustor were obtained from the charts of reference 3; heating values of the fuels are listed in table I (net heat of combustion).

The experimental data used to derive enthalpy values from the charts were: inlet-air total pressure, considered to be represented by the average reading of the 12 total-pressure tubes located in section A-A (fig. 2); inlet-air total temperature, taken as the average reading of the two thermocouples located in section B-B (fig. 2); average combustor-outlet (or turbine-inlet) gas total temperature, taken as the average reading of the 16 thermocouples at section C-C (fig. 2), when the thermocouple values were considered as true values of the total temperature.

RESULTS AND DISCUSSION

Carbon Deposition

The amounts of carbon deposited by the various fuels in the single combustor at simulated engine conditions of altitudes of 20,000 and 35,000 feet, 90-percent normal rated engine speed, and Mach number of 0 are presented in table II. Investigations of some of the fuels were repeated to determine the reproducibility of the data. The average value of the carbon depositions in the two or more repeated runs on each of these fuels is also listed in table II.

The average values of the carbon deposition from table II are plotted against run time in figure 4 for the 20,000-foot-altitude condition; carbon deposition is also shown in figure 5 for a run time of 6 hours and an altitude of 35,000 feet.

As shown in figure 4, the base-stock and high-end-point AN-F-58 fuels (NACA fuels 48-249 and 48-258, respectively) gave values of carbon deposition that increase approximately linearly with run time throughout the range of the experimental program. The carbon-deposition values obtained with the high-aromatic AN-F-58 fuel (NACA fuel 48-279) and with AN-F-32 (NACA fuel 48-306) began to depart from a linear relation after about 4 hours of run time.

Comparison of the data of figure 4 at a run time of 6 hours with data of figure 5 indicates that carbon deposition decreased with increase in altitude. Conversion of the carbon-deposition values to amount of carbon per unit of fuel consumed, however, results in values that are substantially constant. These constant values indicate that, for the limited range of run time and the type of combustor used, carbon deposition varied directly with the weight of fuel consumed. This result was not obtained when carbon deposition was investigated in an annular combustor (reference 2). The order of carbon deposition among the fuels was the same for the different run times at an altitude of 20,000 feet as it was for the run time of 6 hours at an altitude of 35,000 feet (figs. 4 and 5). For a run time of 6 hours and an altitude of 20,000 feet, the order of the fuels with increasing carbon and the amount of carbon deposited (in grams) with each is as follows:

Base-stock AN-F-58 (NACA fuel 48-249) 8.9
High-end-point AN-F-58 (NACA fuel 48-258) 11.3
AN-F-32 (NACA fuel 48-306). 16.5
High-aromatic AN-F-58 (NACA fuel 48-279) 19.0

Because the end-point temperatures (590° F) of the high-end-point AN-F-58 fuel (NACA fuel 48-258) and high-aromatic AN-F-58 fuel (NACA fuel 48-279) are the same, it might be presumed that any difference in the values of carbon deposition of the two fuels would be caused by the differences in aromatic content. The AN-F-32 fuel (NACA fuel 48-306), however, has an end-point temperature of 446° F and gives values of carbon deposition between the values obtained with the two previously mentioned AN-F-58 fuels. Data presented in reference 2 indicate that the volumetric average boiling temperature (arithmetical average of the boiling temperatures at the 10-, 30-, 50-, 70-, and 90-percent evaporated points) is more indicative of the temperature effect on carbon deposition of a fuel than is the end-point temperature. Other data presented in reference 2 show the effect of change in hydrogen-carbon weight ratio of a fuel (resulting from changes in aromatic content) on carbon deposition.

Volumetric average boiling temperatures of the AN-F-58 and AN-F-32 fuels used in the present carbon-deposition investigation were determined from the data of table II. Carbon deposition of the AN-F-58 fuels (figs. 4 and 5) increased with increase in volumetric average boiling temperature at constant aromatic content. The volumetric average boiling temperature of the high-end-point AN-F-58 fuel (NACA fuel 48-258) was 17° F higher than that of the base-stock AN-F-58 fuel (NACA fuel 48-249); its average carbon deposition, at a run time of 6 hours and 20,000-foot-altitude conditions, was 27 percent higher than that of base-stock AN-F-58 fuel (NACA fuel 48-249). The volumetric average boiling temperature of the high-aromatic AN-F-58 fuel (NACA fuel 48-279) was 20° F higher than that of high-end-point AN-F-58 fuel (NACA fuel 48-258); but its average carbon deposition, at the previous conditions, was 68 percent higher than that of high-end-point AN-F-58 fuel (NACA fuel 48-258). Comparison of these values indicates that the increase in carbon deposition of the high-aromatic AN-F-58 fuel (NACA fuel 48-279) over that of the other AN-F-58 fuels was not entirely due to the difference in boiling temperatures, but was also an effect of the increase in aromatic content. Although the AN-F-32 fuel had the highest volumetric average boiling temperature of the four fuels investigated, its value of carbon deposition was exceeded by that of the high-aromatic AN-F-58 fuel. This fact can be explained by the increased aromatic content of the high-aromatic AN-F-58 fuel over that of the AN-F-32 fuel.

An empirical method of correlating carbon-deposition data of 19 fuels with their volumetric average boiling temperature and hydrogen-carbon weight ratio is presented in reference 2. A plot of the carbon-deposition data of the AN-F-58 and AN-F-32 fuels according to the correlation of reference 2 is presented in figure 6. The figure is divided into two quadrants; the left quadrant contains lines of constant hydrogen-carbon weight ratio and volumetric average boiling temperature; the right quadrant contains the weight of carbon deposited. The ordinate of the chart is obtained by moving up the volumetric average boiling temperature to the proper hydrogen-carbon weight-ratio curve. The weight of carbon obtained is then plotted against this value of the ordinate. The same constants relating hydrogen-carbon weight ratio and volumetric average boiling temperature of reference 2 were used for constructing the left quadrant of figure 6. The hydrogen-carbon weight ratios and data for calculating the volumetric average boiling temperatures of the AN-F-58 and AN-F-32 fuels were obtained from table I.

The carbon-deposition data of the four fuels, at any one engine condition, can be approximated by one straight line and demonstrates that the correlation of reference 2 has valid application to the fuels studied herein.

During the 80-hour intermittent run made in connection with the altitude-operational-limit work, it was impractical to weigh the carbon deposits at intervals in order to determine the rate of carbon build-up. Such a procedure would have involved disassembly of the combustor and thus might have disturbed the carbon formations. As an alternative, the liner, dome, and ignition-plug assembly was therefore photographed at successive intervals. Several of the photographs are shown in figures 7 to 9. These photographs indicate that the weight of carbon deposited by the high-aromatic AN-F-58 fuel (NACA fuel 48-279) on the fuel nozzle and primary air louvres increased progressively until the duration of the run had reached about 70 hours, at which time the rate of erosion and burning away of the carbon apparently balanced the rate of its deposition. Carbon formations on the liner apparently approached a maximum after about 40 hours.

As shown in figure 8(a), the ignition plug was fouled after 17 hours of running time at engine conditions of 20,000-foot altitude and 90-percent normal rated engine speed. The ignition plug was cleaned without disturbing the formations on the other parts of the combustor assembly. Ignition-plug fouling again occurred at these engine conditions, as shown in figures 8(b) to 8(d), and required cleaning in each case.

Effect of Carbon Formations on Altitude Operational Limits

Results of the investigation to determine the effects of carbon formations on altitude operational limits are shown in figure 10. Because altitude conditions for engine operational conditions above 60,000 feet could not be simulated, the tailed data points do not necessarily represent altitude limits at the particular engine speed. The other data points do represent altitude limits. Combustion efficiencies at the experimental points that determine the altitude-operational-limit curves are included in the figure.

In general, the operational limits of the high-aromatic AN-F-58 fuel (NACA fuel 48-279) occurred at lower altitudes (for given engine speeds) when investigated using the liner and dome containing carbon deposits from the 80-hour run than when using an initially clean assembly. The difference was of the order of 2500 feet within the range of 60- to 90-percent normal rated engine speed.

In order to preserve as nearly as possible the initial condition of the liner assembly with regard to carbon deposition, it was desirable to hold the altitude-limit experimental run time to a minimum. With this minimum in mind the runs, at given engine speeds, were made at altitude increments of 2500 feet until the highest altitude was determined at which engine operation requirements were attained.

A photograph of the combustor assembly (fig. 7), made immediately after the upper curve in figure 10 was established, shows that the high-aromatic AN-F-58 fuel (NACA fuel 48-279) deposited very little carbon during the altitude-limit runs made with an initially clean liner assembly. The condition of the combustor assembly, with regard to carbon formations, after the 80-hour run is shown in figure 8(d). The lower curve of figure 10 was then determined with the initial condition of the assembly as shown in figure 8(d). A photograph (fig. 9), made of the assembly immediately after the lower curve of figure 10 was determined, indicates that the amount of carbon deposited during the 80-hour run was actually reduced during the altitude-limit runs.

At an engine speed of 53-percent normal rated (fig. 10), the same altitude limit was obtained with the initially clean combustor assembly as with the assembly containing carbon formations. The combustion efficiency was about 9 percent higher, however, when using the assembly containing carbon. This difference is in agreement with data presented in reference 4, which indicate that combustion efficiency increases with carbon build-up on the fuel nozzle. The high combustion efficiency obtained with the combustor containing carbon deposits (lower curve) at the high engine speeds cannot, however, be entirely attributed to carbon because the low altitude at which the data were obtained would also contribute to higher efficiency.

SUMMARY OF RESULTS

From carbon-deposition investigations of three AN-F-58 fuels and one AN-F-32 fuel in a J33 single combustor, the following results were obtained:

1. Carbon deposition increased with increase in volumetric average boiling temperature at constant aromatic content and with increase in aromatic content of the AN-F-58 fuels as shown by data plotted on the basis of an empirical correlation previously established.

2. Values of carbon deposition obtained with the AN-F-32 fuel were exceeded only by the values obtained with the AN-F-58 fuel nearest the maximum limits of boiling temperature and aromatic content. For a run time of 6 hours, the values were 16.5 and 19.0 grams for the AN-F-32 and the AN-F-58 fuels, respectively.

3. Altitude operational limits of the high-aromatic AN-F-58 fuel occurred at altitudes approximately 2500 feet lower when the liner and dome assembly contained carbon deposits than when it did not.

4. The ignition plug was fouled with carbon after 17 hours of intermittent operation with a fuel approaching the maximum limits of the AN-F-58 specification at simulated engine conditions of 20,000 feet altitude and 90-percent normal rated engine speed.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Dittrich, Ralph T., and Jackson, Joseph L.: Altitude Performance of AN-F-58 Fuels in J33-A-21 Single Combustor. NACA RM E8L24, 1949.

2. Wear, Jerrold D., and Jonash, Edmund R.: Carbon Deposition of 19 Fuels in an Annular Turbojet Combustor. NACA RM E8K22, 1949.

3. Turner, L. Richard, and Lord, Albert M.: Thermodynamic Charts for the Computation of Combustion and Mixture Temperatures at Constant Pressure. NACA TN 1086, 1946.

4. Dittrich, Ralph T.: Effects of Fuel-Nozzle Carbon Deposition on Combustion Efficiency of Single Tubular-Type, Reverse-Flow, Turbojet Combustor at Simulated Altitude Conditions. NACA TN 1618, 1948.

5. Gooding, Richard M., and Hopkins, Ralph L.: The Determination of Aromatics in Petroleum Distillates. Papers Presented before Div. Petroleum Chem., Am. Chem. Soc. (Chicago, Ill.), Sept. 9-13, 1946, pp. 131-141.

1113

TABLE I - SPECIFICATIONS AND ANALYSES OF FUELS USED

NACA fuel	Specifications		Analysis			
	AN-F-58	AN-F-32	AN-F-58			AN-F-32
			48-249	48-258	48-279	48-306
A.S.T.M. distillation D 86-46, °F						
Initial boiling point	----------	----------	110	110	110	336
Percentage evaporated						
5	----------	----------	135	137	133	350
10	----------	410 (max.)	157	157	164	356
20	----------	----------	192	198	215	360
30	----------	----------	230	248	273	365
40	----------	----------	272	291	327	370
50	----------	----------	314	332	370	375
60	----------	----------	351	373	407	380
70	----------	----------	388	410	437	387
80	----------	----------	427	450	464	394
90	425 (min.)	490 (max.)	473	500	501	405
Final boiling point	600 (max.)	572 (max.)	560	590	590	446
Residue, (percent)	1.5 (max.)	1.5 (max.)	1.0	1.0	1.0	1.0
Loss, (percent)	1.5 (max.)	1.5 (max.)	1.0	1.0	1.0	1.0
Freezing point, °F	-76 (max.)	-76 (max.)	< -76	< -76	< -76	------
Accelerated gum, (mg/100 ml)	20 (max.)	8.0 (max.)	2.9	12.4	17.3	0.0
Air-jet residue, (mg/100 ml)	10 (max.)	5 (max.)	2.6	4.8	8.0	1.0
Sulfur, (percent by weight)	0.50 (max.)	0.20 (max.)	0.03	0.04	0.04	0.02
Aromatics, (percent by volume) A.S.T.M. D-875-46T	30 (max.)	20 (max.)	17	17	26	------
Silica gel[a]	----------	----------	19	19	29	15
Specific gravity	----------	0.850 (max.)	0.769	0.775	0.806	0.831
Viscosity, (centistokes at -40° F)	10.0 (max.)	10.0 (max.)	2.67	2.94	4.26	------
Bromine number	14.0 (max.)	3.0 (max.)	13.8	13.3	12.4	------
Reid vapor pressure, (lb/sq in.)	5-7	----------	5.4	5.1	4.8	------
Hydrogen-carbon ratio	----------	----------	0.163	0.161	0.150	0.154
Net heat of combustion (Btu/lb)	18,200 (min.)	----------	18,640	18,690	18,480	18,530
Hydrocarbon analyses, (percent by volume)						
Single-ring aromatics			15.0	13.2	14.8	------
Fused-ring aromatics			3.0	4.1	12.8	------
Unfused two-ring aromatics			0.5	1.5	1.4	------
Olefin			7.1	6.2	5.3	------
Nonaromatic cyclo-paraffin ring			15.7	16.7	14.3	------
Nonaromatic paraffin and paraffin side chain			58.7	58.3	51.4	------

NACA

[a]Determined by modified method of reference 5.

TABLE II - CARBON DEPOSITION OF THREE AN-F-58 FUELS

AND AN-F-32 FUEL IN SINGLE COMBUSTOR

[Simulated engine speed, 90-percent normal rated]

Fuel ↓ / Run time (hr.) →	Carbon deposited, grams				
	Simulated altitude, ft				
	20,000				35,000
	2	4	6	10	6
Base-stock AN-F-58 (NACA fuel 48-249)	4.0 2.5 2.7	5.9 6.0 6.3	9.6 7.8 9.4	14.8 14.9 ----	5.9 ------ ------
Average	3.1	6.1	8.9	14.9	------
High-end-point AN-F-58 (NACA fuel 48-258)	3.2 3.3	7.3 7.5	10.5 12.1	19.7 ----	7.0 ------
Average	3.3	7.4	11.3	----	------
High-aromatic AN-F-58 (NACA fuel 48-279)	6.1 7.2	11.4 15.0	17.2 20.7	26.7 ----	10.1 13.7
Average	6.7	13.2	19.0	----	11.9
AN-F-32 (NACA fuel 48-306)	6.2 6.7	12.5 11.8	15.8 17.2	22.7 26.1	11.0 11.2
Average	6.5	12.2	16.5	24.4	11.1

NACA

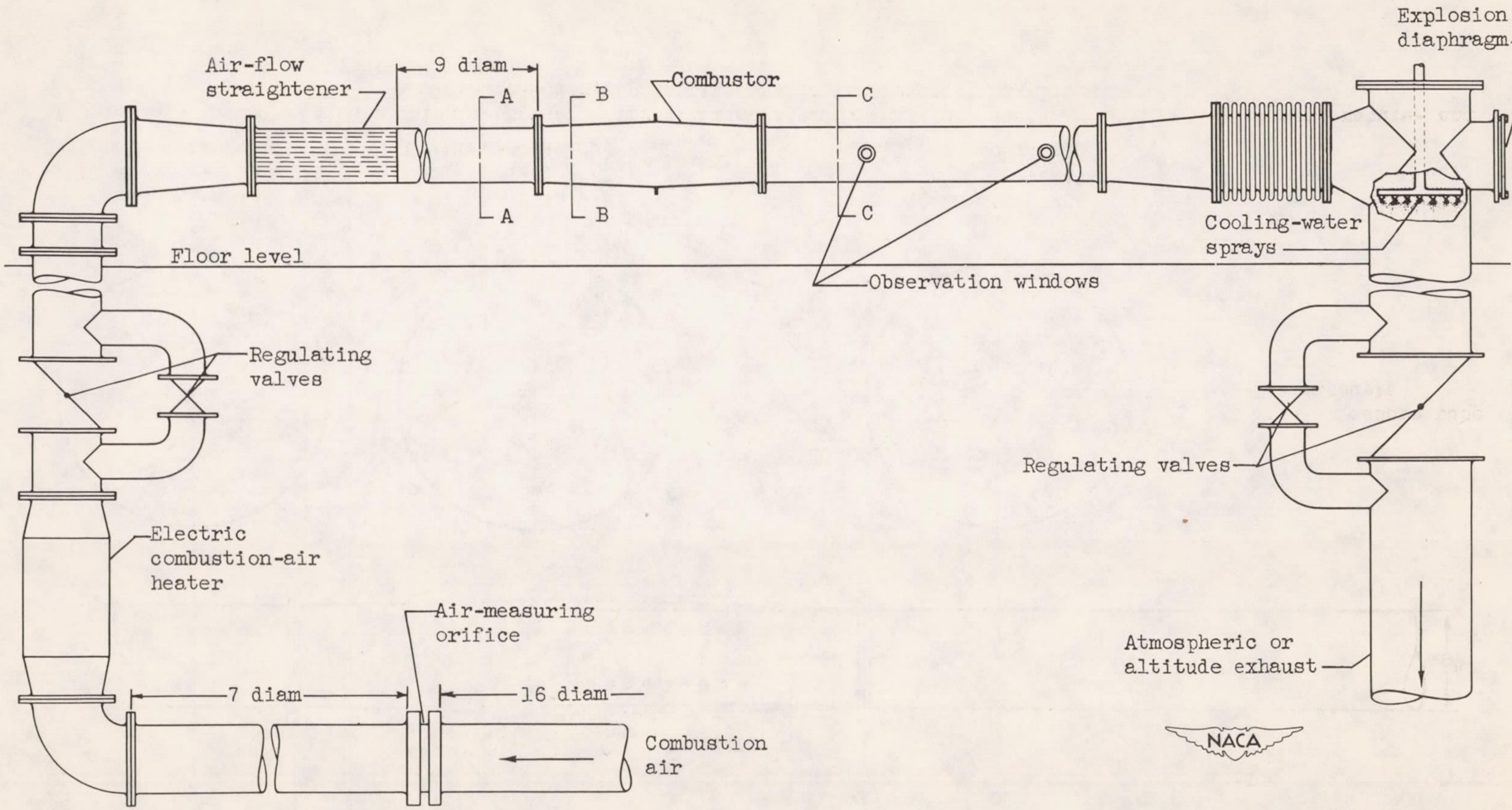


Figure 1. - Single-combustor installation and auxiliary equipment. Instrumentation planes, A-A, B-B, and C-C.

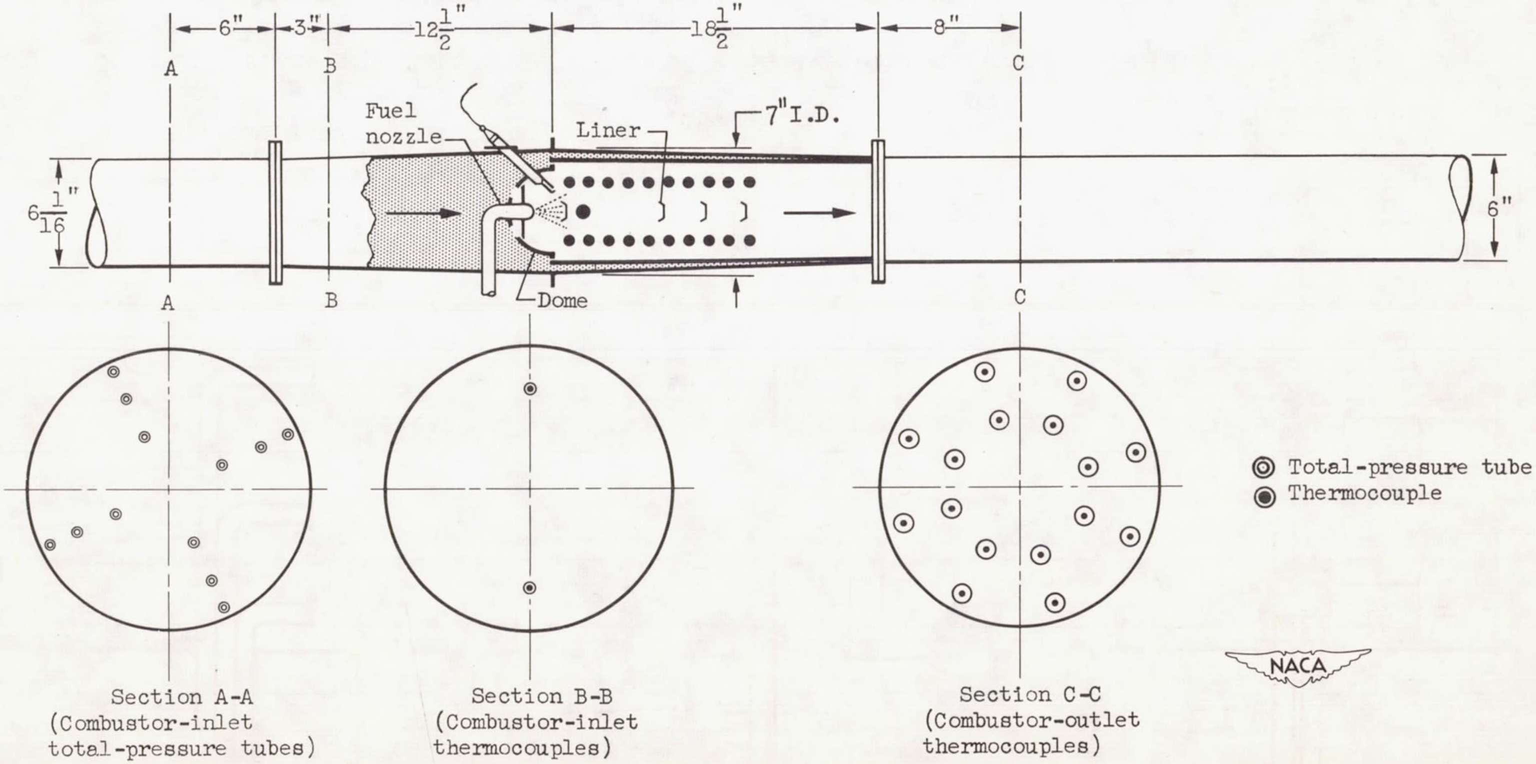


Figure 2. - Cross section of single-combustor installation showing auxiliary ducting and location of temperature- and pressure-measuring instruments in instrumentation planes.

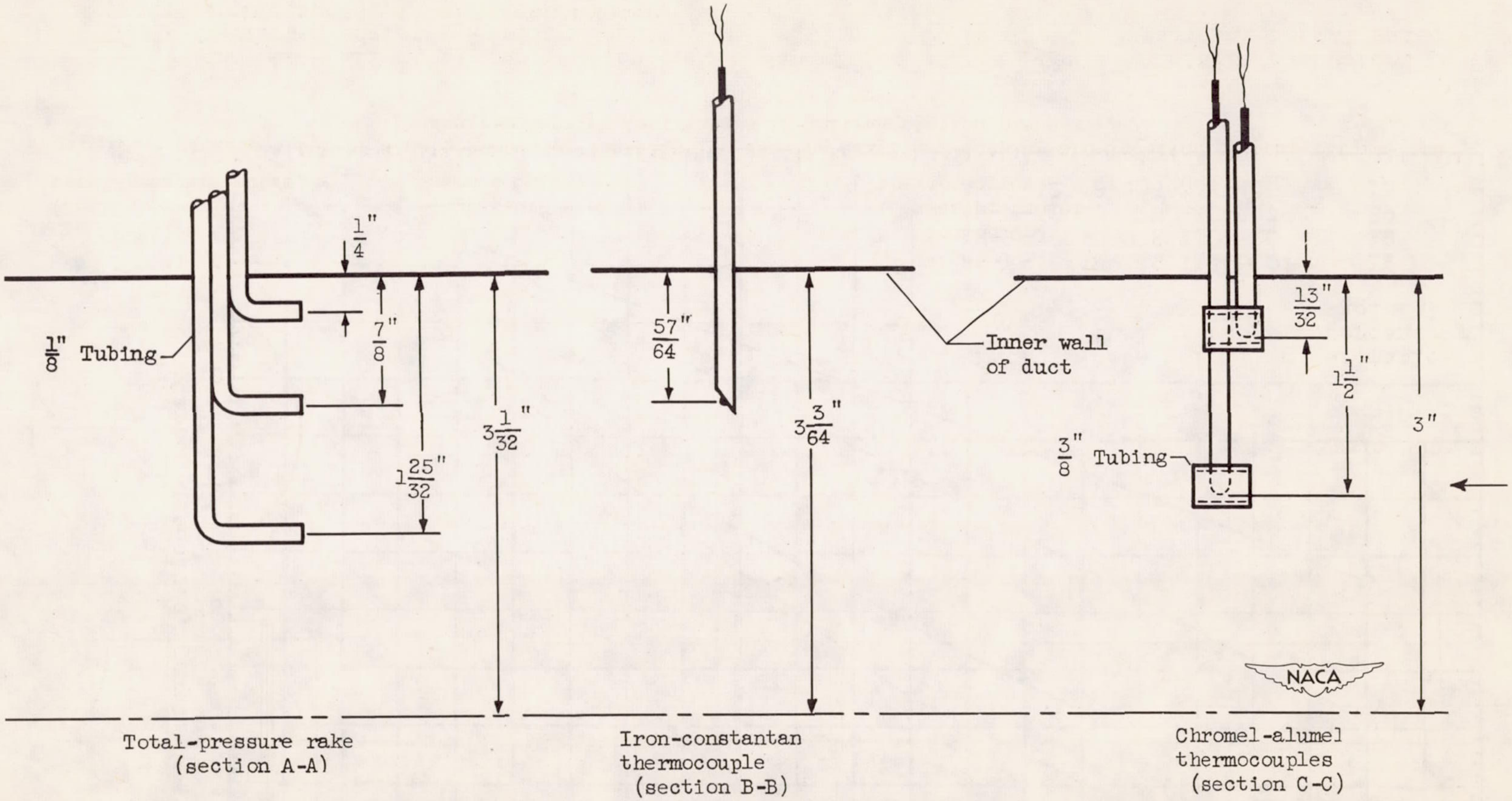


Figure 3. - Construction details of temperature- and pressure-measuring instruments.

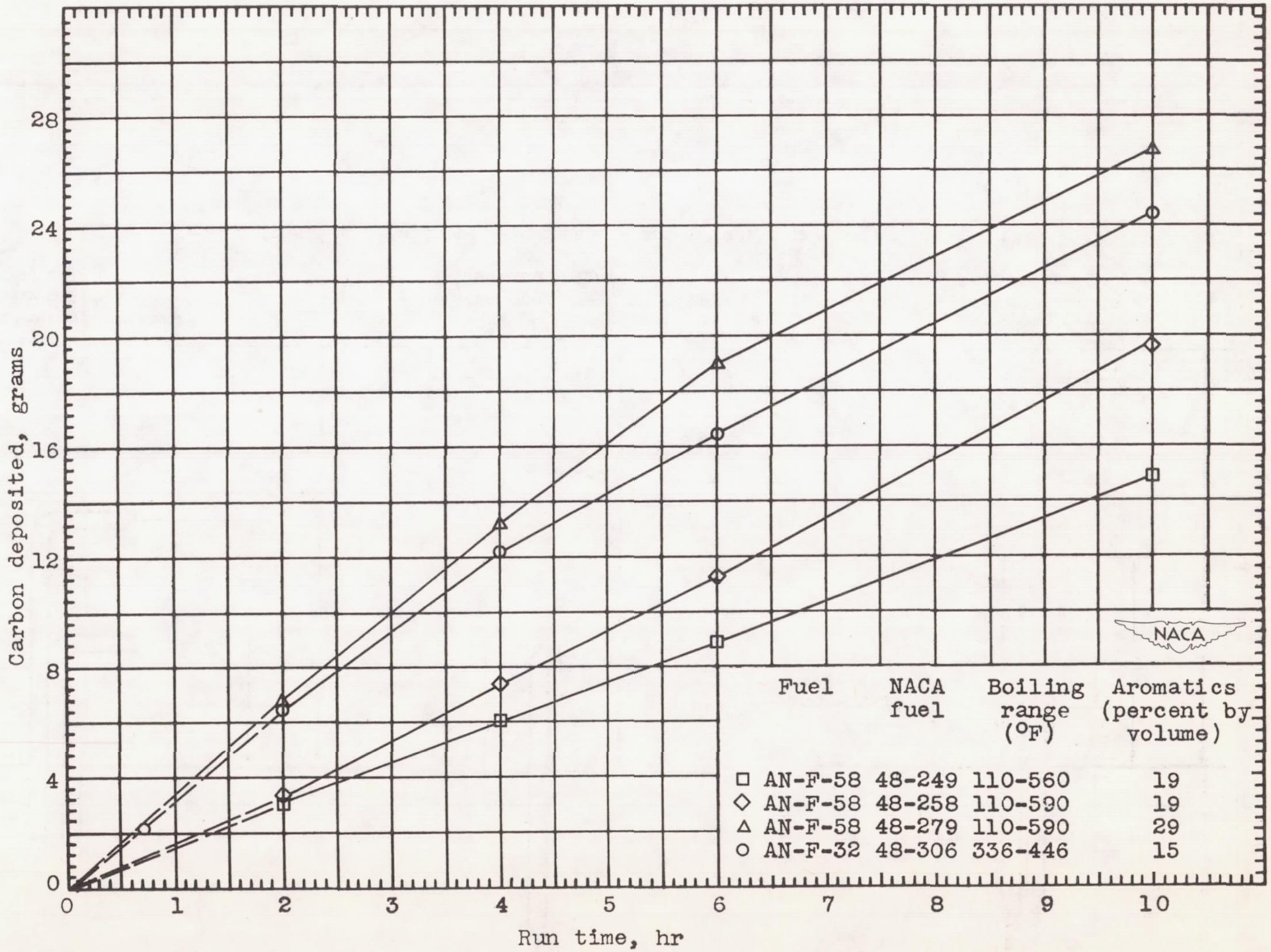


Figure 4. - Effect of run time on carbon deposition of four fuels in single combustor. Simulated engine operating conditions: altitude, 20,000 feet; 90-percent normal rated engine speed; flight Mach number, 0.

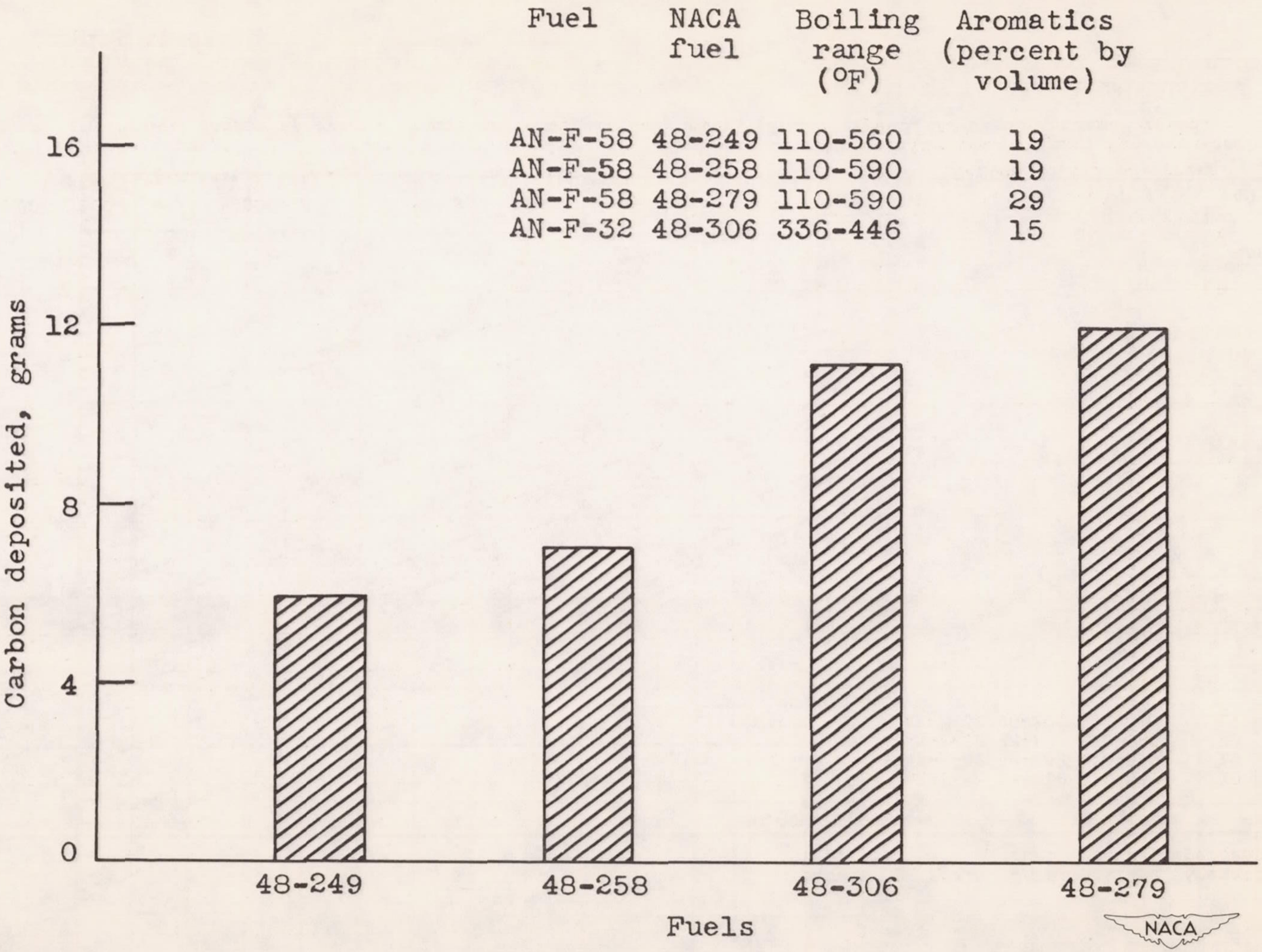


Figure 5. - Carbon deposition of four fuels in single combustor. Run time, 6 hours; simulated engine operating conditions: altitude, 35,000 feet; 90-percent normal rated engine speed; flight Mach number, 0.

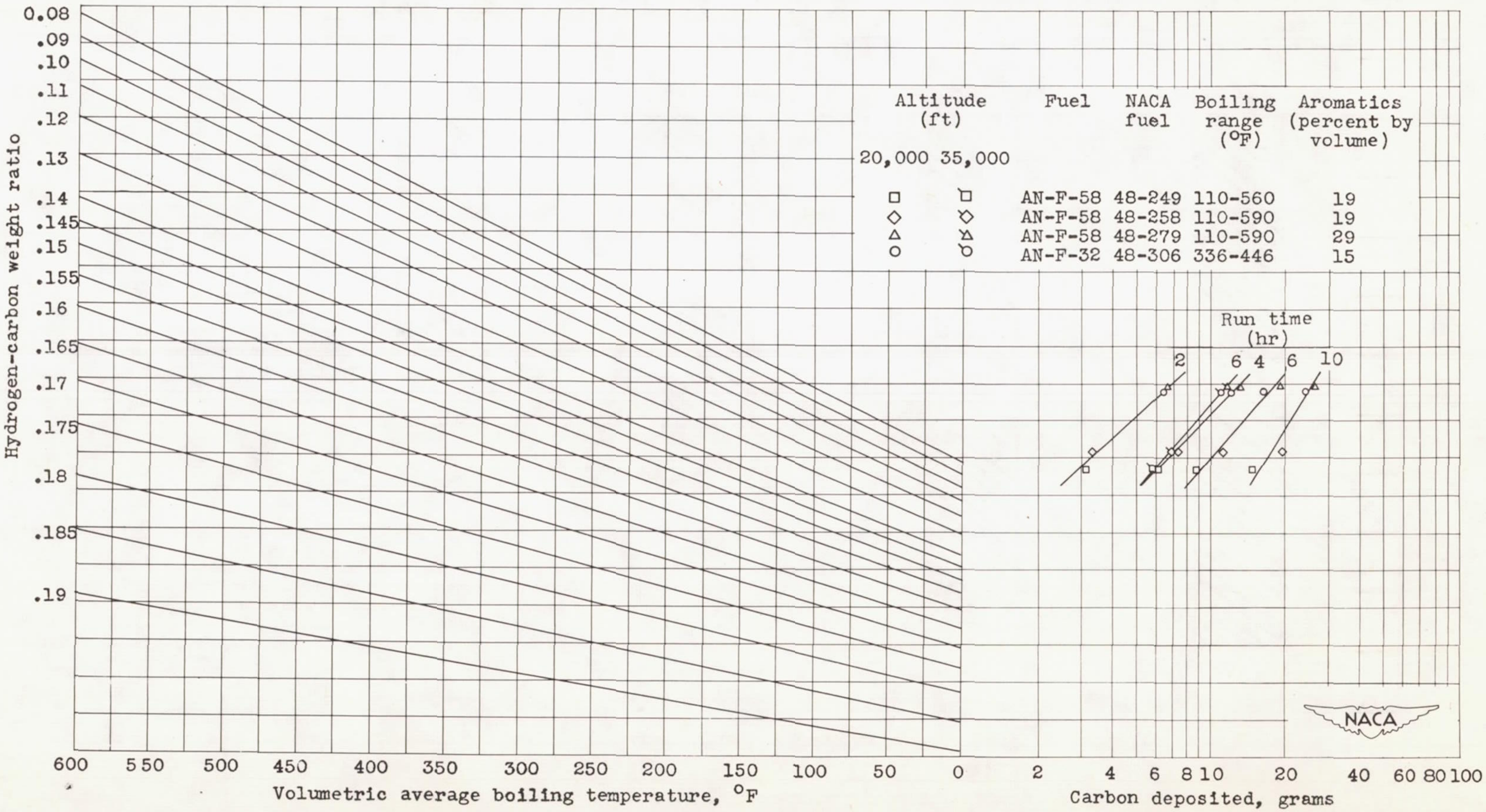


Figure 6. - Carbon deposition of four fuels as determined by volumetric average boiling temperature, hydrogen-carbon weight ratio, and engine operating condition in single combustor. Engine speed, 90-percent normal rated.

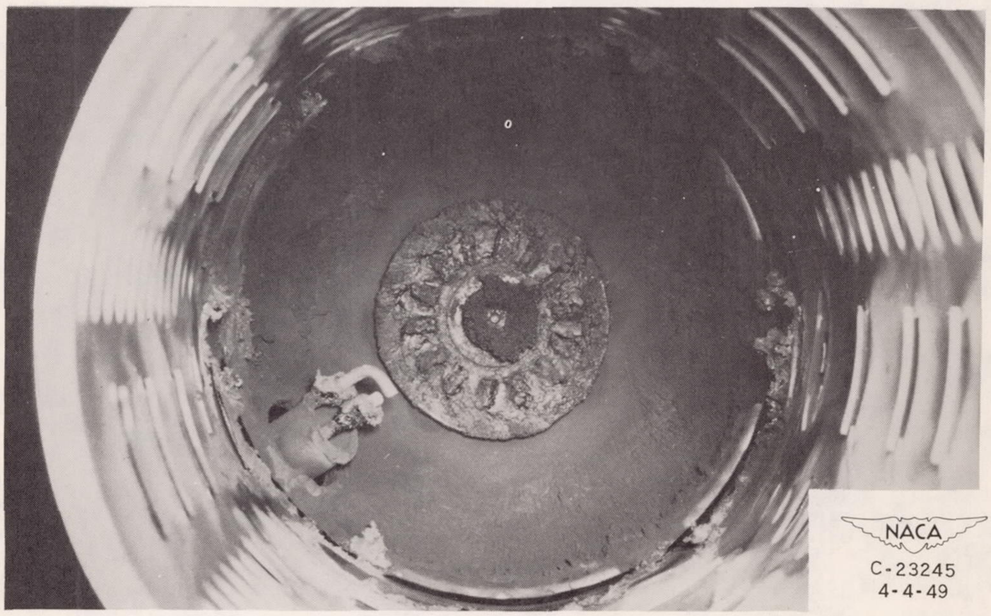
1113

Figure 7. - Carbon deposits in single combustor obtained from altitude-operational-limit determinations made with initially clean combustor assembly. Fuel, high-aromatic AN-F-58 (NACA fuel 48-279).

1113

(a) Run time, 17 hours.

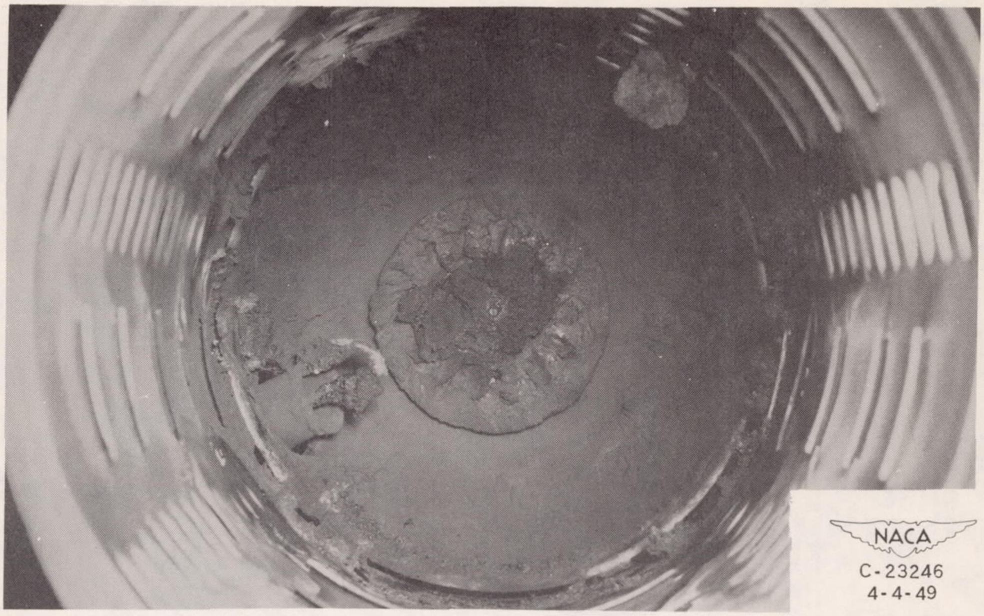
Figure 8. - Carbon deposits in single combustor. Fuel, high-aromatic AN-F-58 (NACA fuel 48-279); engine conditions: altitude, 20,000 feet; 90-percent normal rated engine speed; flight Mach number, 0.



(b) Run time, 43 hours.

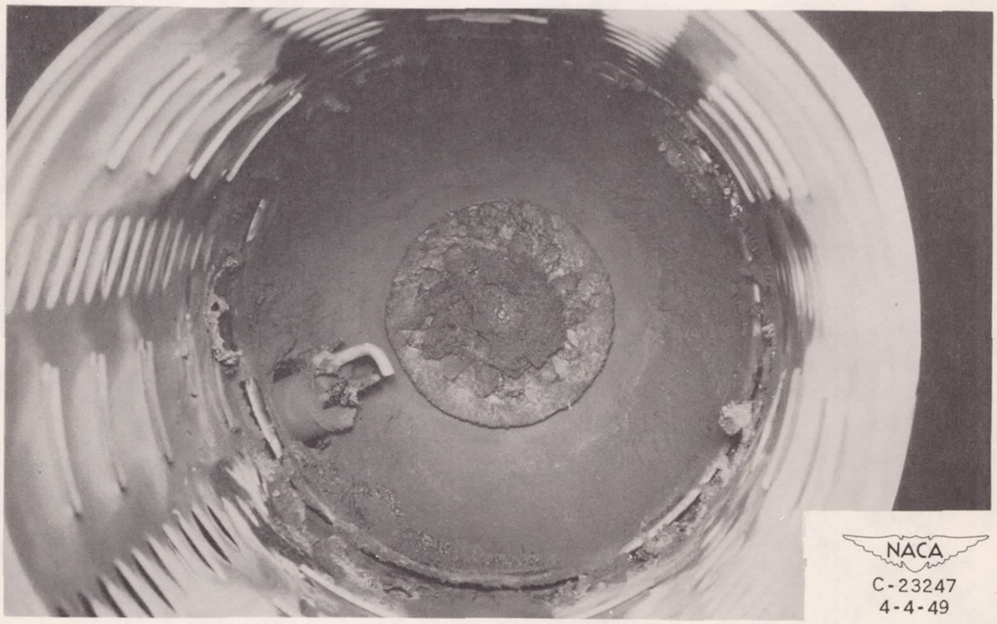
Figure 8. - Continued. Carbon deposits in single combustor. Fuel, high-aromatic AN-F-58 (NACA fuel 48-279); engine conditions: altitude, 20,000 feet; 90-percent normal rated engine speed; flight Mach number, 0.

1113



(c) Run time, 68 hours.

Figure 8. - Continued. Carbon deposits in single combustor. Fuel, high-aromatic AN-F-58 (NACA fuel 48-279); engine conditions: altitude, 20,000 feet; 90-percent normal rated engine speed; flight Mach number, 0.



(d) Run time, 80 hours.

Figure 8. - Concluded. Carbon deposits in single combustor. Fuel, high-aromatic AN-F-58 (NACA fuel 48-279); engine conditions: altitude, 20,000 feet; 90-percent normal rated engine speed; flight Mach number, 0.

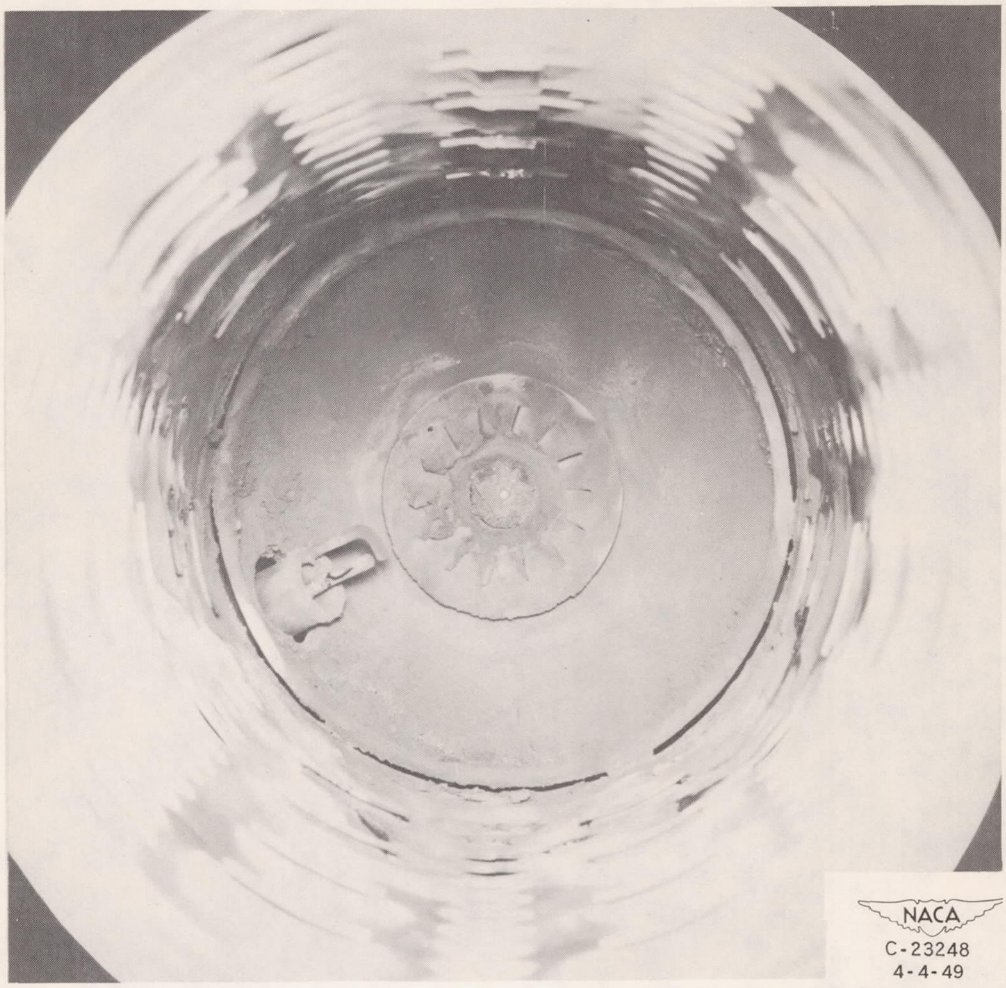


Figure 9. Carbon deposits in single combustor, remaining after altitude-operational-limit determinations made with combustor assembly initially containing deposits from 80-hour run. Fuel, high-aromatic AN-F-58 (NACA fuel 48-279).

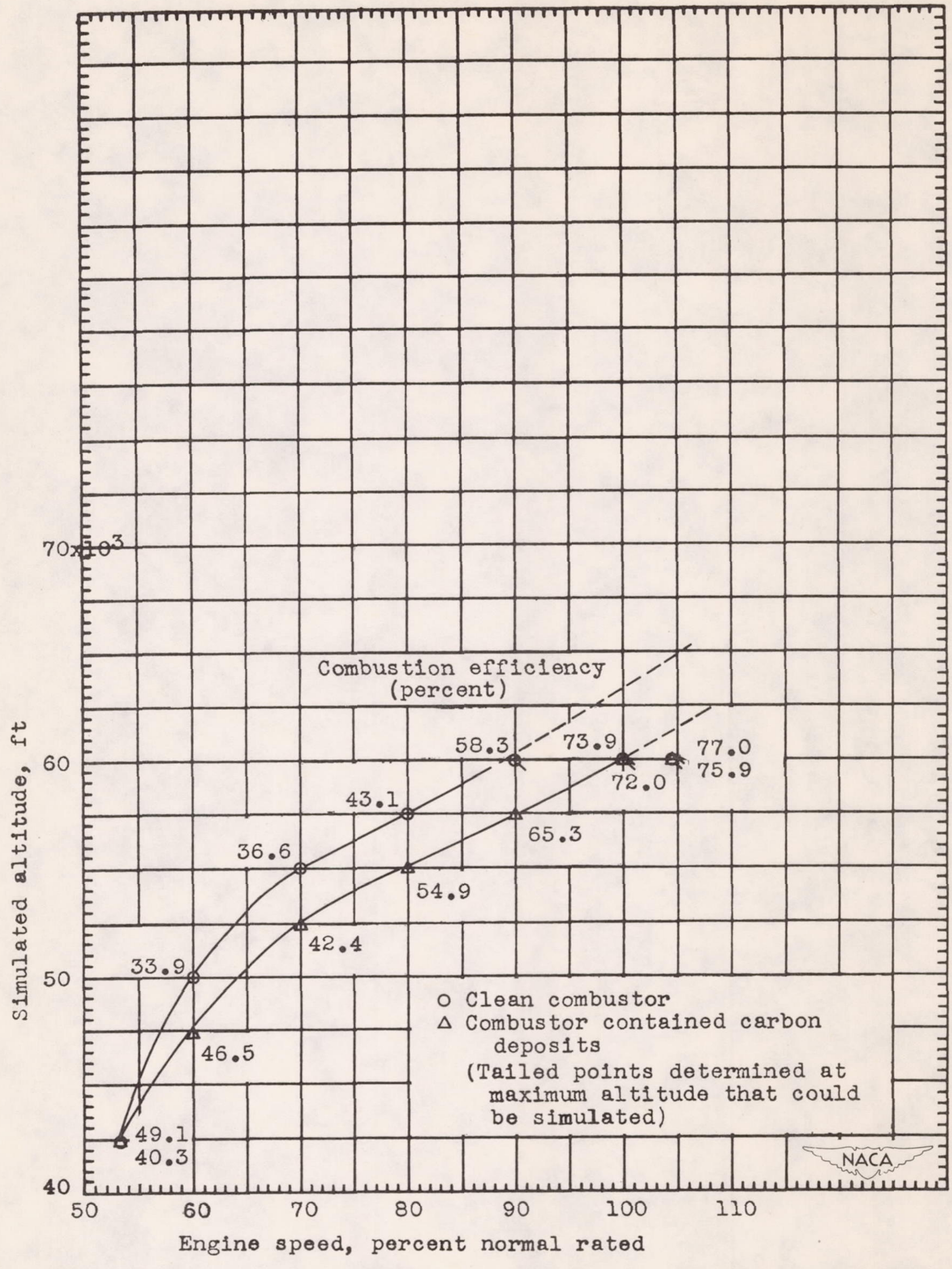


Figure 10. - Altitude operational limits of high-aromatic AN-F-58 fuel (NACA fuel 48-279) as affected by carbon deposits in single combustor.